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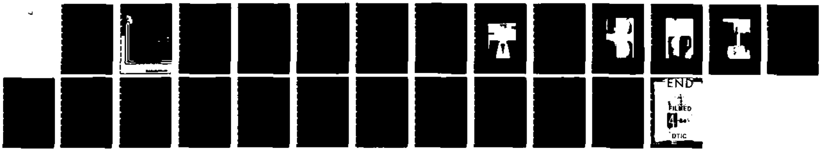

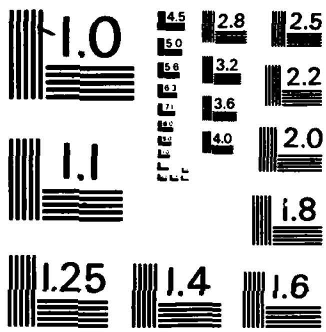

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USAARL REPORT NO. 84-1

UH-60 SHOULDER HARNESS LEAD-IN STRAP FAILURE ANALYSIS

By
Ted A. Hundley

BIODYNAMICS RESEARCH DIVISION

October 1983

U.S. ARMY AEROMEDICAL RESEARCH LABORATORY
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20. ABSTRACT

Shoulder harness lead-in strap failures have occurred in several UH-60 Blackhawk helicopter accidents with crewmembers being injured as a result. An investigation into possible failure causes was conducted. The two most likely causes found were incorrect installation of the seat insert guide and an increase in stress in the lead-in strap caused by the radius of bend at the point where the strap passes through the seat back. Test showed that incorrect installation of the seat insert guide caused a significant reduction in the failure load of the webbing. Tests also showed that a reduction in failure load occurred when the webbing was pulled over a radiused corner. The first problem was solved by removing and reinstalling the seat insert guides. The second problem can be dealt with by using a higher-strength lead-in strap.

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INTRODUCTION

The U.S. Army's newest transport helicopter, the UH-60 Blackhawk, was designed to provide a significant amount of protection for aircraft occupants in case of a crash. However, in two separate crashes the shoulder harness lead-in strap on at least one of the pilot/copilot seats failed. In another crash, a failure of the lead-in strap occurred at the looped end where the shoulder harness straps attach (see Figure 1 for identification of items).

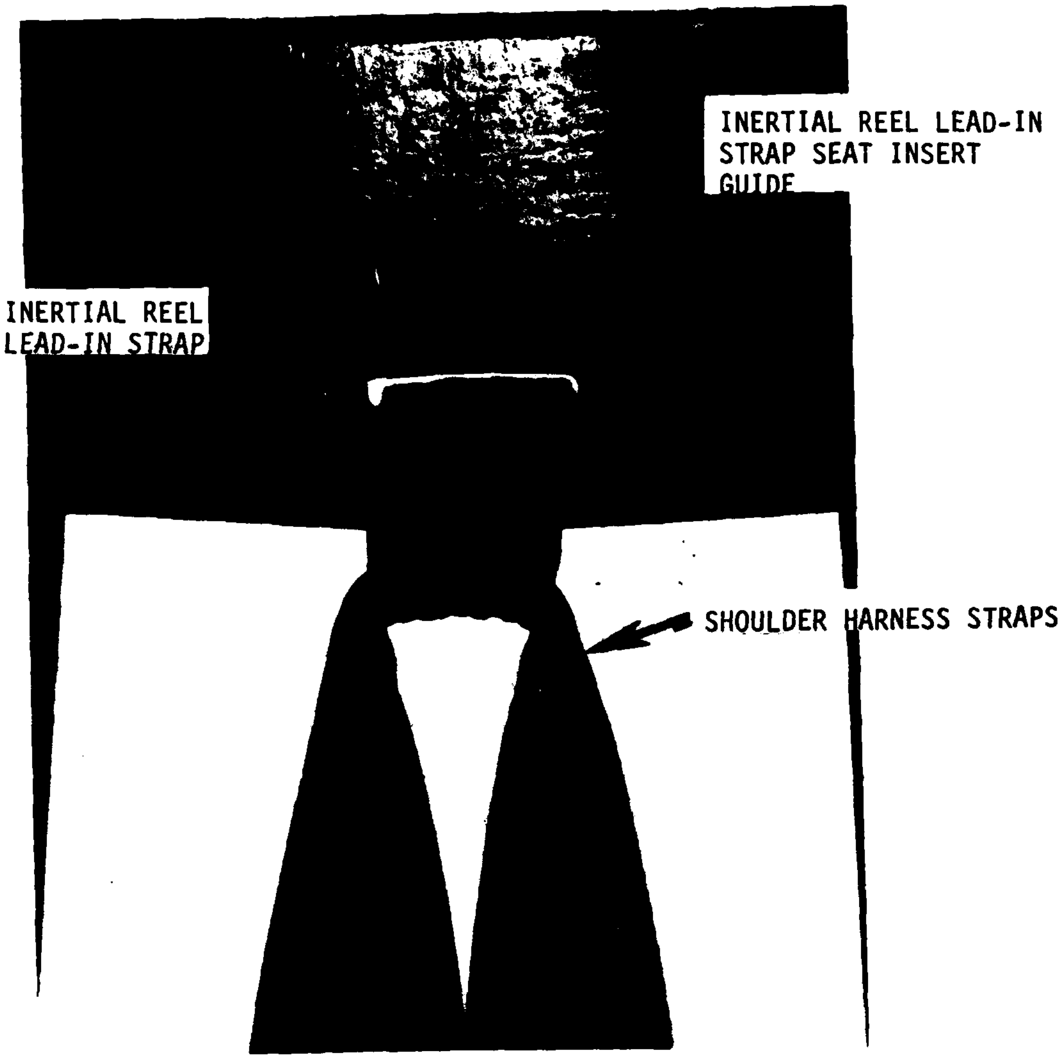
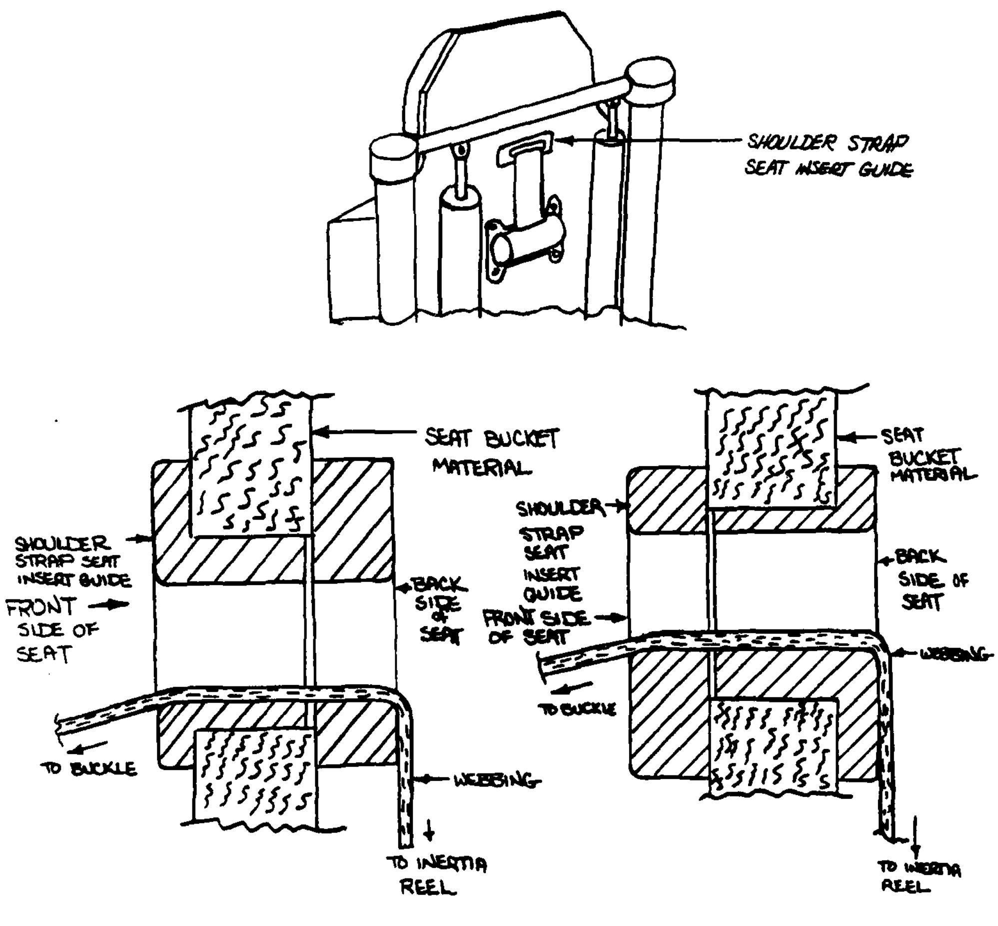


Figure 1. Location of Blackhawk Seat Restraint System Components.

Two potential causes for the failures were identified. The first was improperly installed lead-in strap seat insert guides. In the first two lead-in strap failures, the insert guides were installed reversed and upside down (Figure 2). In this orientation, the lead-in strap loads deformed the lower rear half of the guide and exposed a sharp edge to the strap. This may have caused a stress concentration or may have cut the strap resulting in a failure at a lower-than-designed load. The guides have since been removed and reinstalled correctly.



CROSS-SECTIONAL VIEW OF INCORRECT SEAT INSERT INSTALLATION

CROSS-SECTIONAL VIEW OF CORRECT SEAT INSERT INSTALLATION

Figure 2. Illustration of Correct and Incorrect Installation of Seat Insert Guide.

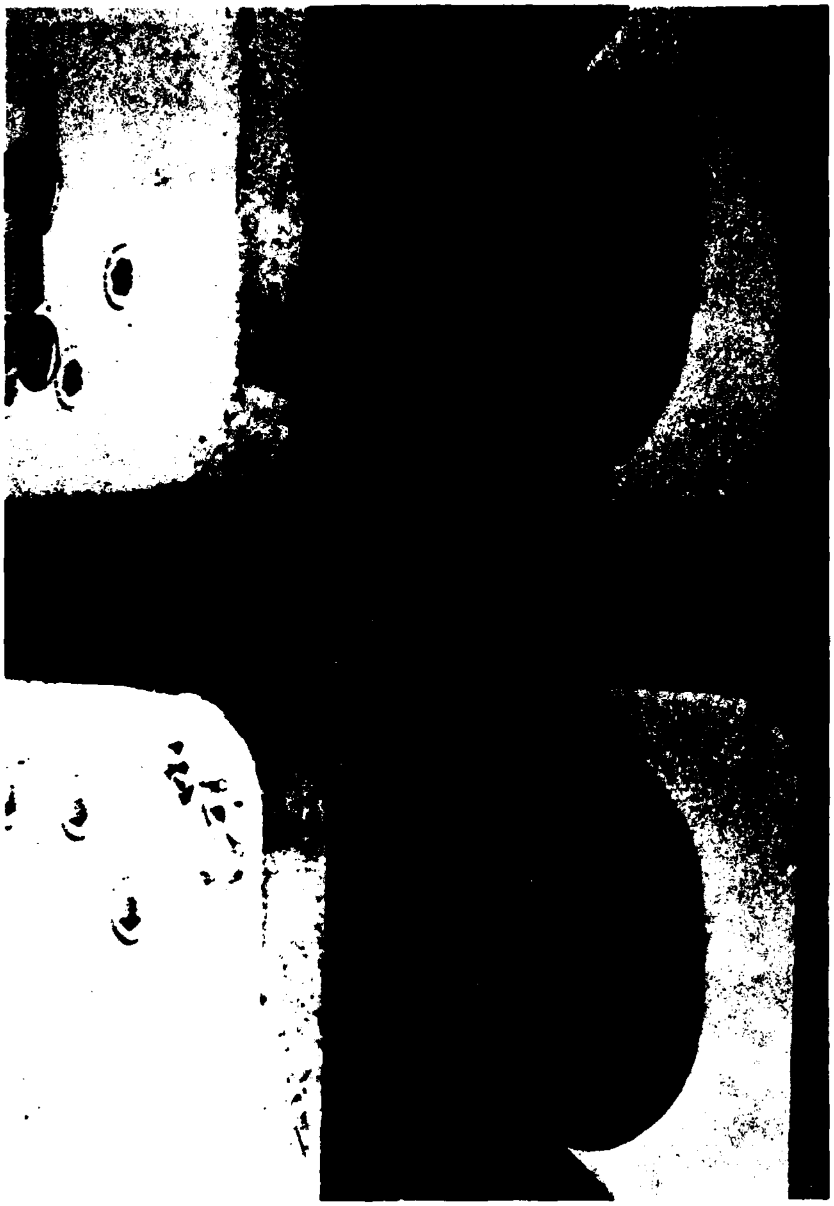


Figure 3. Webbing Test for Basic Tensile Strength Using Sedam Grips.

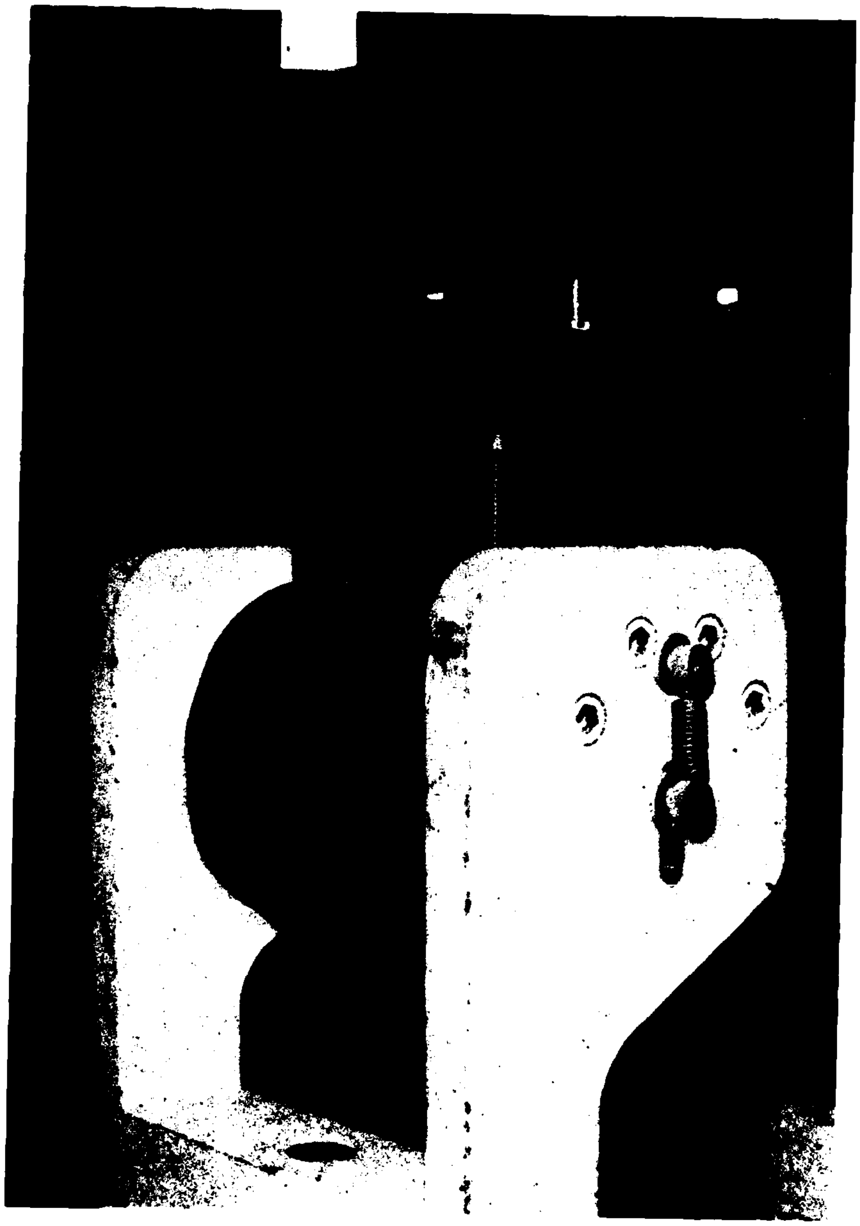


Figure 4. Test Fixture for Simulating Longitudinal Loading of Shoulder Harness Webbing Over Seat Insert Guide.

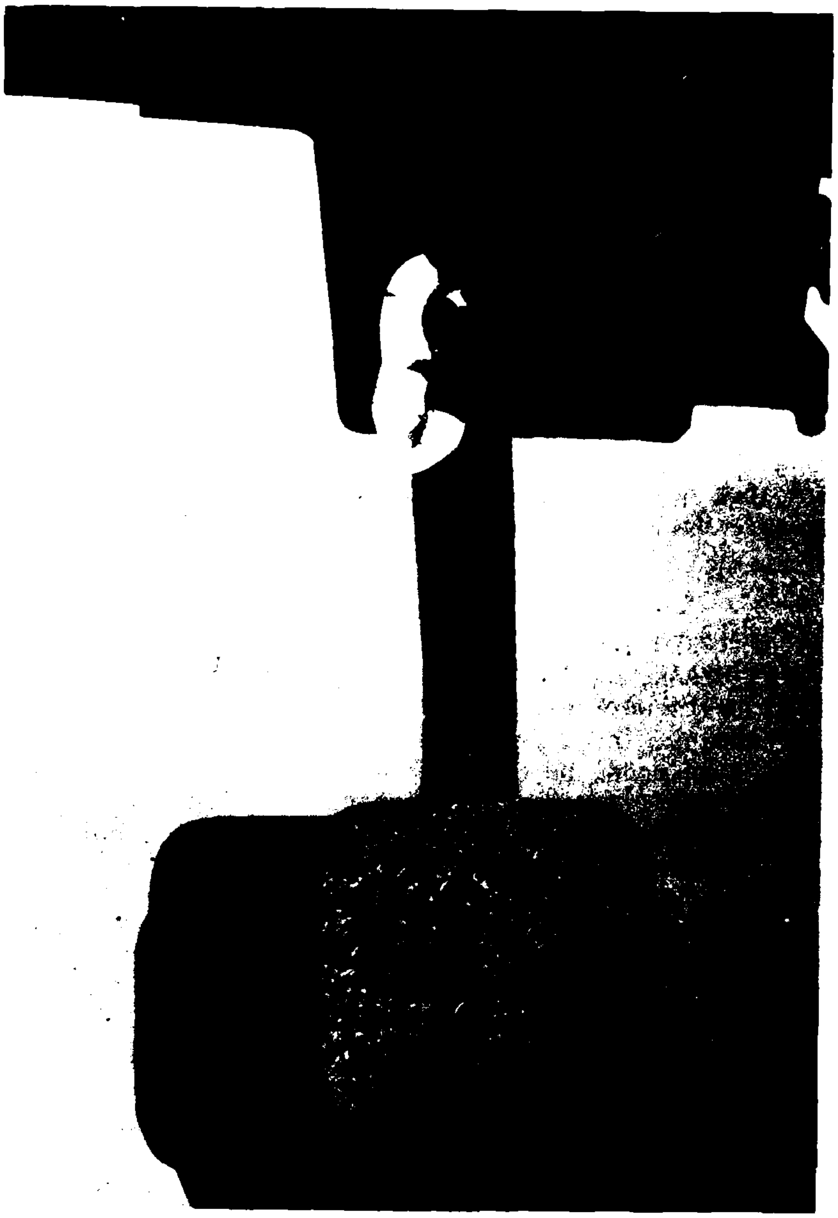


Figure 5. Test Fixture for Simulating Combined Lateral-Longitudinal Loading of Shoulder Harness Webbing Over Seat Insert Guide.

The other potential cause for failure is the stress concentration caused by the ninety-degree bend in the lead-in strap as it comes up the back of the seat from the inertia reel and goes through the seat insert guide to the seat occupant. The stress concentration is compounded by side loads which cause the webbing to bunch up at the side of the insert guide. In order to determine the failure loads for various combinations of strap material and loading geometry, independent test programs were conducted at Pacific Scientific Company, Anaheim, CA; Sikorsky Aircraft, Inc., Stratford, CT; and at the U.S. Army Aeromedical Research Laboratory (USAARL), Fort Rucker, AL.

METHODS AND MATERIALS

The basic piece of apparatus employed was a Tinius-Olsen universal test machine. It is a low-speed material tester that provides tension or compression testing. Sedam grips were used to hold the webbing for the basic tensile strength test (Figure 3). Two test fixtures were fabricated to represent potential loading conditions in a crash. The first fixture represented a purely longitudinal load (Figure 4). The second fixture represented a combination of longitudinal load and lateral loading that resulted in a force vector inclined at a 60-degree angle from a line perpendicular to the front of the seat (Figure 5).

Two series of tests were performed: one before the UH-60 Crashworthiness Conference held at USAARL on 19-20 May 1982 and one after the conference. The initial series of tests were performed on Type X-854 webbing, a product of Murdock Webbing Company, Inc., Central Falls, RI. This webbing is the type used in the production model UH-60 Blackhawk. As a result of information communicated during the cited UH-60 conference, the second series of tests included not only the production webbing (Murdock X-854), but also two other webbings for the purpose of comparison: Murdock Q-921 webbing and MIL-W-25361 Type III webbing obtained from Pacific Scientific. All webbings were made of low-elongation polyester-type fiber. The X-854 minimum breaking strength is stated as 6,000 pounds. The Q-921 webbing is an experimental-type that Murdock developed for Pacific Scientific. Murdock stated that it has a breaking strength of 8,740 pounds in pure tension. The MIL-W-25361 Type III webbing is required to have a minimum breaking strength of 7,000 pounds.

The purpose of the first test series was to obtain some production webbing failure load data for the purpose of discussion. Only Murdock X-854 webbing was tested. Basic tensile strength tests were done to establish a basic strength value for comparison. Subsequently, tests were run using the two test fixtures to determine failure loads under potential crash loading geometry. The amount of webbing available was limited, so only a small number of tests could be done. For each sample, the sequence of testing was the following: two straight pulls to determine the basic tensile strength

of the webbing; one test used the combined lateral-longitudinal loading fixture; and two final tests used the longitudinal loading fixture.

For the second series, only basic tensile strength tests and combined lateral-longitudinal loading tests were performed. Because both Pacific Scientific and Sikorsky Aircraft were doing longitudinal loading tests and because there only was a very small amount of the Murdock Q-921 webbing available, the focus at USAARL was on the more severe lateral-longitudinal loading.

RESULTS AND DISCUSSION

In the first series, the pure tension failure loads for the Murdock X-854 webbing were 6,740 pounds and 7,080 pounds, an average of 6,910 pounds. Loads were applied at the rate of 10 inches per minute. The failure loads for the longitudinal loading using a seat insert guide installed upside down and reversed were 3,320 pounds and 3,010 pounds, an average of 3,165 pounds. That is a 54 percent reduction in average breaking strength when compared to the pure tensile load test. The failure load for the one combined lateral-longitudinal loading test was 2,960 pounds, a 57 percent reduction in breaking relative to that of the pure tensile breaking strength.

The second test series utilized webbing samples obtained from Pacific Scientific. Basic tensile strength tests were done on the MIL-W-25361 Type III and the Murdock X-854 webbing, but not on the Murdock Q-921 webbing due to the limited quantity available. The basic tensile failure loads for the Type III webbing were 8,000 pounds, 8,200 pounds, and 8,300 pounds, an average of 8,167 pounds. The Murdock X-854 basic tensile failure loads were 6,900 pounds, 6,880 pounds, and 7,080 pounds, an average of 6,953 pounds. All the other tests in this series used the combined lateral-longitudinal test fixture. All testing was done at a rate of 10 inches per minute. Three tests were run for each webbing type. The results are shown in Table 1.

TABLE 1

WEBBING FAILURE LOADS FOR COMBINED LATERAL-LONGITUDINAL LOADING

Webbing Type	1st Test (lb.)	2d Test (lb.)	3d Test (lb.)	Average (lb.)	Reduction from Basic Tensile Strength
MIL-W-25361 Type III	3,350	3,200	3,260	3,270	60%
Murdock X-854	2,800	2,940	2,900	2,730	61%
Murdock Q-921	3,240	3,360	3,360	3,320	62%*

* Basic tensile strength used was 8,740 lbs. as stated by Murdock Webbing Company, Inc.

Sikorsky and Pacific Scientific notified USAARL of their findings. Sikorsky found the average failure load for Murdock X-854 webbing in pure tension was 6,540 pounds. Pacific Scientific found the average failure load was 6,613 pounds. When pulled through a correctly-installed seat insert guide in a longitudinal loading condition, Sikorsky found that the average failure load for Murdock X-854 webbing was 4,733 pounds while Pacific Scientific tests resulted in an average failure load of 4,883 pounds. The percentage reduction in breaking strength using the correctly-installed seat insert guide was 27.6 percent in Sikorsky's test and 26.2 percent in Pacific Scientific's test.

Both companies also tested the Murdock Q-921 webbing using longitudinal loading through a correctly-installed seat insert guide. The average failure load reported by Sikorsky was 6,250 pounds. The average failure load reported by Pacific Scientific was 6,130 pounds. Using Murdock's tensile strength statement of 8,740 pounds for Q-921, the reduction in tensile strength for Sikorsky's test was 28.5 percent and for Pacific Scientific's test was 29.9 percent.

In all cases a significant reduction in tensile strength was shown when the webbing was forced to change directions by bending over the seat insert guide. The greatest reductions in failure loads were caused by the combined lateral-longitudinal loading and by the incorrect installation of the seat insert guide. The seat insert guide installation problem has been corrected, but the combined lateral-longitudinal loading problem remains as a potential threat.

In an attempt to understand the stress concentration failure mechanism, USAARL contacted several Army, Navy, and Air Force research organizations to determine if any substantive research had been done on the problem. Although several of the individuals contacted said that they were aware of the reduction in failure loads caused by small radius fittings used with webbing, they could not identify any specific research on the problem. One report was found which dealt with the failure loads of high-speed parachute webbing (Williams and Benjamin, 1960, p. 54-56). The report states that dynamic failure loads of parachute webbings were only 60 to 74 percent of the failure loads determined statically. It theorized the cause was the dynamic stress wave effect which caused high localized stresses at the solid mounting points where the stress waves reversed direction. It also stated that it was common practice to design parachute suspension lines and risers using a tensile strength of one-half the static tensile strength. The report did not address stress concentrations caused by bends in the webbing.

An article found in the *Textile Research Journal* (Schoppee and Skelton, 1974) dealt with the effect of bend radius on the tensile failure strength of individual fibers. Although the article's authors' findings cannot be directly applied to woven webbing, the results found for individual fibers may suggest a trend that also will be found in woven webbing. In particular, they presented a curve showing that high tenacity polyester fiber, which is the material used in the restraint harness webbings addressed herein, is sensitive to the radius of curvature around which it is bent. Their data (Figure 6)

show that the breaking strength of the fiber is reduced by approximately 30 percent when pulled around a cylinder with a diameter no more than 10 times the diameter of the fiber. As the diameter of the cylinder gets smaller, the breaking strength of the fiber continues to decrease. When the ratio of the diameter of the fiber to the diameter of the cylinder approaches 1/20 (i.e., 5 percent), the breaking strength is reduced by 50 percent.

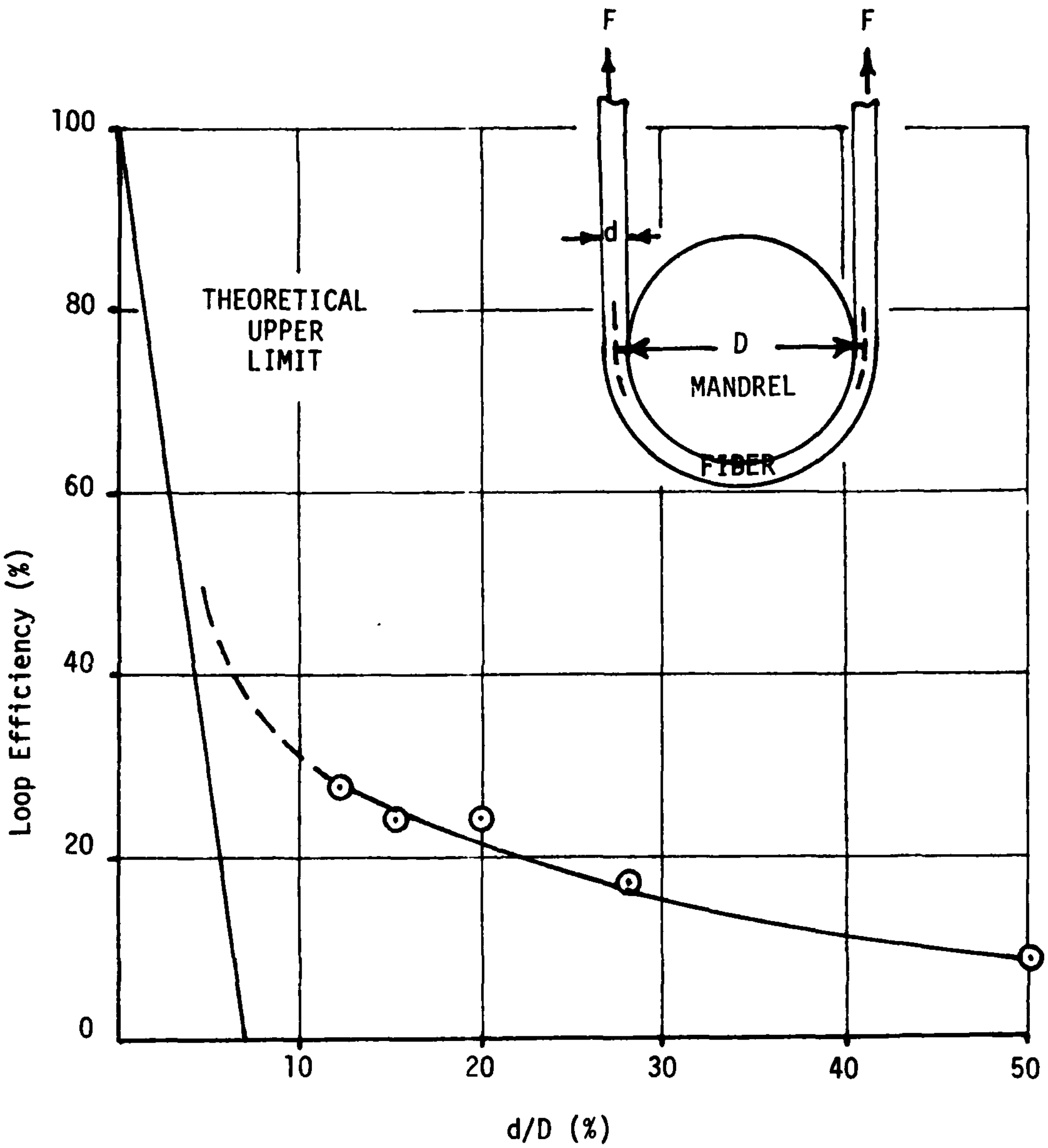


Figure 6. Single Fiber Loop Efficiency for High Tenacity Polyester Fiber (Figure redrawn from Bending limits of some high-modulus fibers, *Textile Research Journal*, Vol. 44, No. 12, Dec 1974, p. 972).

CONCLUSIONS AND RECOMMENDATIONS

The conclusion of this investigation is that the shoulder harness restraint systems failed at lower than expected loads because of the combination of the incorrect installation of the seat insert guide and the stress concentration caused by the bending of the webbing as it comes up the back of the seat and through the seat insert guide. As a result of the communication of the early findings of this author to the manufacturer, the incorrect installation of the seat insert guides has been corrected. Further research into the effect of bending radius on webbing stress concentration is, however, recommended.

For the interim, the decision by the manufacturer to replace the Murdock X-854 with the higher-strength Q-921 webbing may be an adequate solution. The design load of 4,000 pounds for the shoulder harness initially was given a 50 percent safety factor and is satisfied through the use of 6,000 pound class webbing. In light of the findings to date, a safety factor of 100 percent would appear more reasonable. This can be attained by using 8,000 pound tensile strength webbing.

With the use of increased strength webbing, it may be that the inertia reel itself will prove to be the weakest link in the restraint system. The problem of an inertia reel that is designed for 4,000 pounds already has been partially addressed by the manufacturer. Modifications have been made that increase the strength to 5,000 pounds. However, it may be prudent to investigate the possibility of designing an inertia reel capable of withstanding loads of 8,000 pounds or more.

The importance of proper restraint cannot be overstated. With stronger aircraft frames and seats, the load on restraint harnesses can be expected to increase. Failure of the restraint harness system may become the deciding factor in determining whether or not an aviator survives an accident. Therefore, it may be desirable to over-design in order to build in a high probability of successful performance.

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Williams, R. B., and Benjamin, R. J. 1960. *Analysis of webbing impact data and determination of optimum instrumentation to be used in conjunction with the impact of webbing.* Wright-Patterson Air Force Base, OH: Wright Air Development Division, Air Research and Development Command. WADC TR 59-694.

APPENDIX A

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